An 8-GeV cw Superconducting Linac for Fermilab's Future

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The purpose of this letter is to call attention to attractive and innovative ideas to greatly enhance Fermilab's proton source capability. Bill Foster pointed out the advantages of using a superconducting 8-GeV H^- linac based on ILC technology [1] to fill the Main Injector (MI). Part of the appeal of Foster's idea, besides facilitating beam power of about a megawatt at 120 GeV from the MI, is its potential excess capacity. Of particular interest in that regard is the potential to also provide about a megawatt of beam power at 8 GeV in order to enable a vigorous muon program including stopping beams, a neutrino factory, and a muon collider.

For a neutrino factory based on a 50-GeV muon storage ring, the muon lifetime is about a millisecond, so the natural repetition rate for refilling such a storage ring is about a kHz. That high rep rate suggests a natural modification of Foster's idea, as has been previously suggested [2]: *to run the linac cw*. There are many advantages to running a superconducting linac cw, as demonstrated for example at CEBAF. With continuous beam, it takes only 125 μA of beam current to provide one megawatt at 8 GeV. At that current, beam loading and transient issues are negligible, and a few one megawatt klystrons running cw can power the whole linac, leading to a very simple and robust system. As Bob Webber recently pointed out in a private communication, the room-temperature front end is the challenging part of a cw linac. An entirely new idea is that a low-energy conventional cyclotron running at an rf frequency of 54.166 MHz, $1/24^{th}$ of 1.3 GHz, looks like a promising way to address that challenge, since cyclotrons naturally produce cw beam. At some modest energy, the transition would be made to the linac structures proposed by Foster.

H^- charge-stripping injection into the Recycler would be used to accumulate the protons intended to make muons. Since the revolution frequency of the Recycler is about 90 kHz, 90 turns would be injected at a time. The longitudinal beam structure in the Recycler is not optimal for muon production, so the beam would be extracted to another 8-GeV storage ring with a much smaller circumference and a large aperture, where about ten turns would be injected using transverse stacking. The smaller ring would have rf systems to rebunch the protons longitudinally before extracting to a target for muon production.

In a 750-GeV on 750-GeV muon collider, the muon lifetime is about 15.6 msec, so the luminosity lifetime due to muon decays is half of that, or about 8 msec. Now suppose that the muon beams in the collider consist of 8 bunches on 8 bunches and that we adopt the

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[1] G. W. Foster and J. A. MacLachlan, Proceedings of LINAC 2002, Gyeongju, Korea

[2] M. Popovic and R. P. Johnson, "Muon Acceleration in a Superconducting Proton Linac", NuFact05, Frascati, Italy

refilling strategy of replacing only the oldest pair of bunches at a time. With that strategy, one kHz is also a natural repetition rate for refilling a muon collider, so the same system that is optimal for a neutrino factory is also optimal for the front end of a muon collider. The transformation from a neutrino factory to a muon collider would require a coalescing ring to rebunch the muons at 50 GeV into single bunches for further acceleration to 750 GeV. This muon coalescing scheme is one of the subjects of a recent Phase II STTR project by Muons, Inc. and Fermilab [3].

It is assumed here that, shortly before the beginning of every 1.333 sec MI ramp, the Recycler would be used instead to accumulate protons destined for the Main Injector. At 125 μA, it would take 89 msec or 7900 turns to accumulate enough protons to provide one megawatt at 120 GeV from the MI. Accommodating the injection of so many turns at a time is another challenge for implementing the cw linac idea. A big issue in that regard is the survival and lifetime of the stripping foil. Modulating the beam current to somewhat larger values during the injection of protons destined for the MI can substantially reduce the number of turns that must be injected. Conventional transverse “painting” injection schemes can reduce the probability for passage of circulating protons through the stripping foil on subsequent turns after injection to about 5%. Longitudinal stacking by injecting off-center into 54.166 MHz buckets can be used to further reduce the probability of subsequent foil hits. In that context it should be mentioned that 54.166 MHz corresponds closely to the 603rd harmonic of the Recycler revolution frequency, so synchronous transfer is possible. It is likely that reasonable stripping foil lifetimes can be achieved by rotating a 600 $\mu g/cm^2$ diamond stripping foil, though of course that must be simulated and tested.

Somewhat surprisingly, emittance growth is not the issue because multiple scattering scales very favorably with beam energy, and the emittance of the circulating beam will intentionally be painted to a much larger value than that of the linac beam anyway. The biggest issue for this and all ideas involving high beam power is reducing uncontrolled beam losses to acceptable levels. Laser stripping of the low-energy H^- beam can be used to kill unwanted bunches in order to make beam-handling manipulations cleaner.

The ideas suggested herein take optimal advantage of existing lab infrastructure with reasonable modifications and elaborations to enable a dynamic program for Fermilab’s intermediate-term future. If an 8-GeV linac is in the cards, cw seems to be the way to go.

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[3] C. M. Ankenbrandt et al. “Muon Bunch Coalescing” PAC07. And DOE STTR grant DE-FG02-05ER86252